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(54) **VAPOR CELL ATOMIC CLOCK PHYSICS PACKAGE**

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G04F 5/14 (2006.01)

(52) **U.S. Cl.**
CPC ***G04F 5/14*** (2013.01); ***G04F 5/145*** (2013.01); *Y10T 29/49117* (2015.01)

(58) **Field of Classification Search**
CPC H03B 17/00; G04F 5/145
USPC 331/94.1, 3; 29/825
See application file for complete search history.

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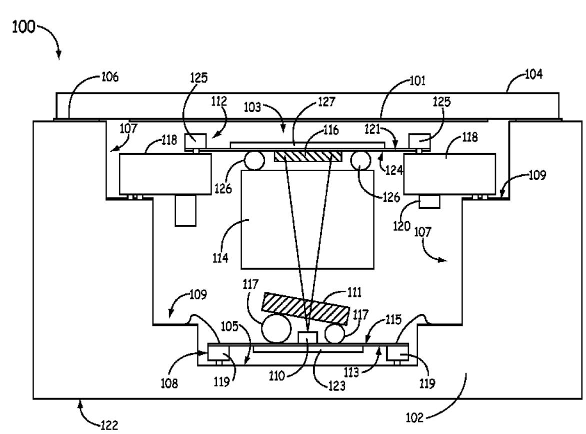
(57) **ABSTRACT**

In an example, a chip-scale atomic clock physics package is provided. The physics package includes a body defining a cavity having a base surface and one or more side walls. The cavity includes a first step surface and a second step surface defined in the one or more side walls. A first scaffold mounted to the base surface in the cavity. One or more spacers defining an aperture therethrough are mounted to the second step surface in the cavity. A second scaffold is mounted to a first surface of the one or more spacers spans across the aperture of the one or more spacers. A third scaffold is mounted to a second surface of the one or more spacers in the cavity and spans across the aperture of the one or more spacers. Other components of the physics package are mounted to the first, second, and third scaffold.

20 Claims, 5 Drawing Sheets



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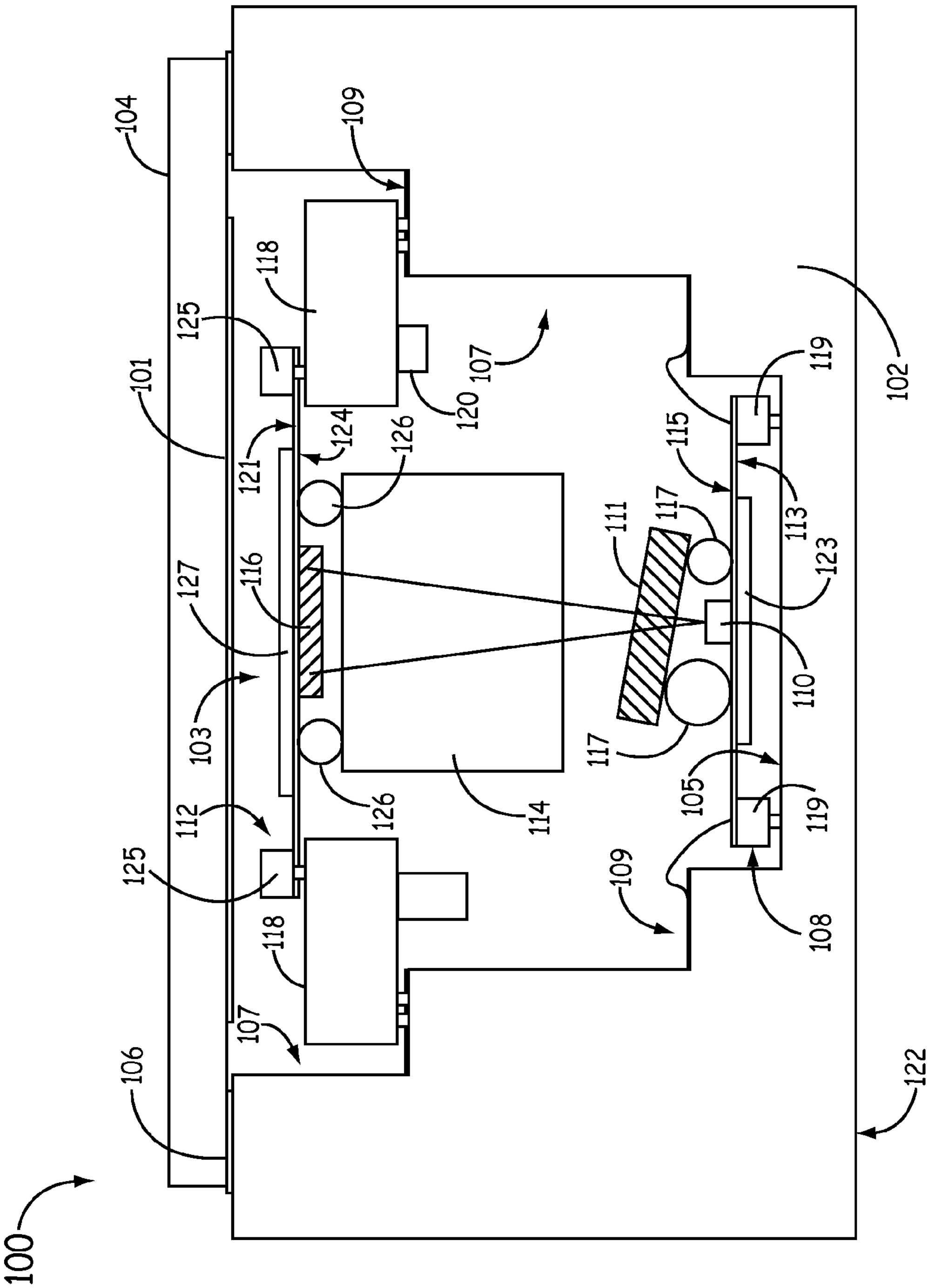
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FIG. 1

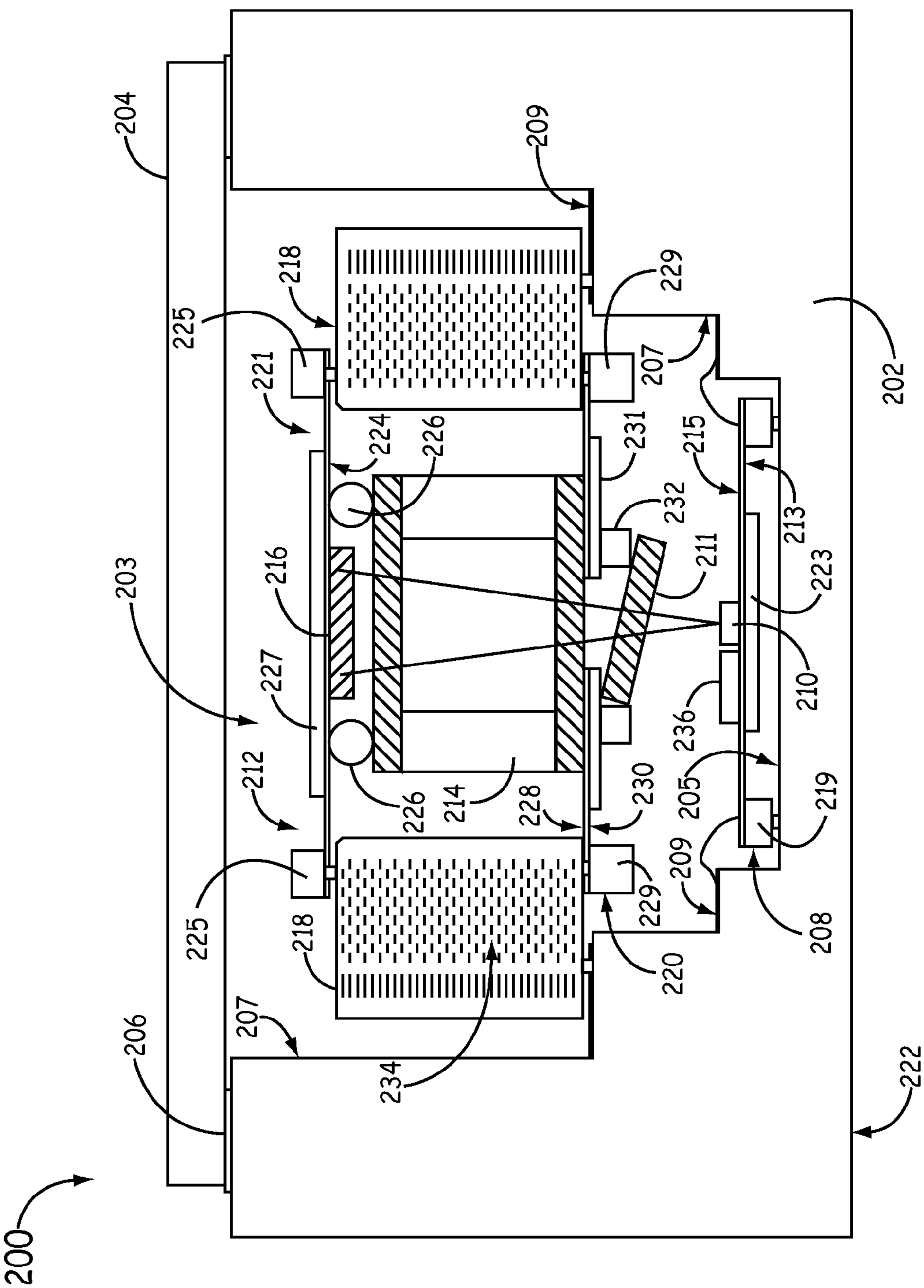
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FIG. 2

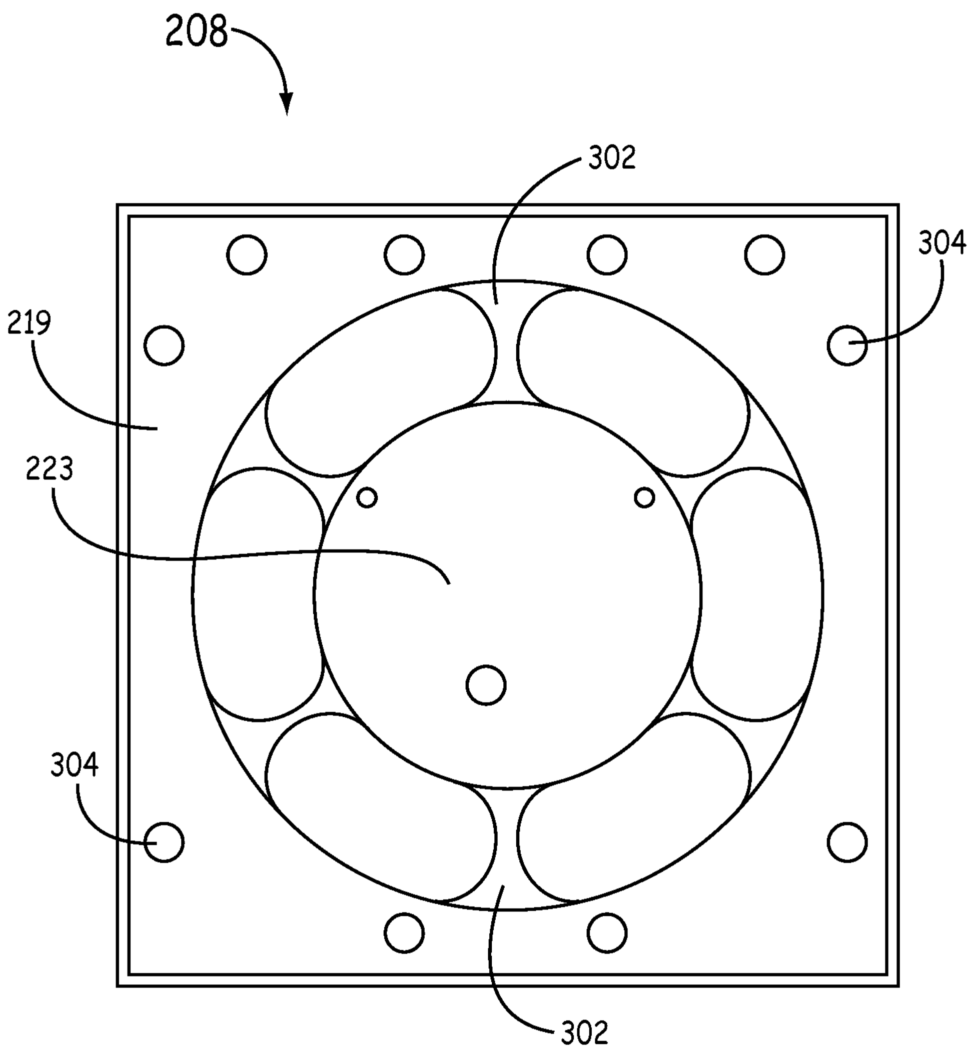

FIG. 3

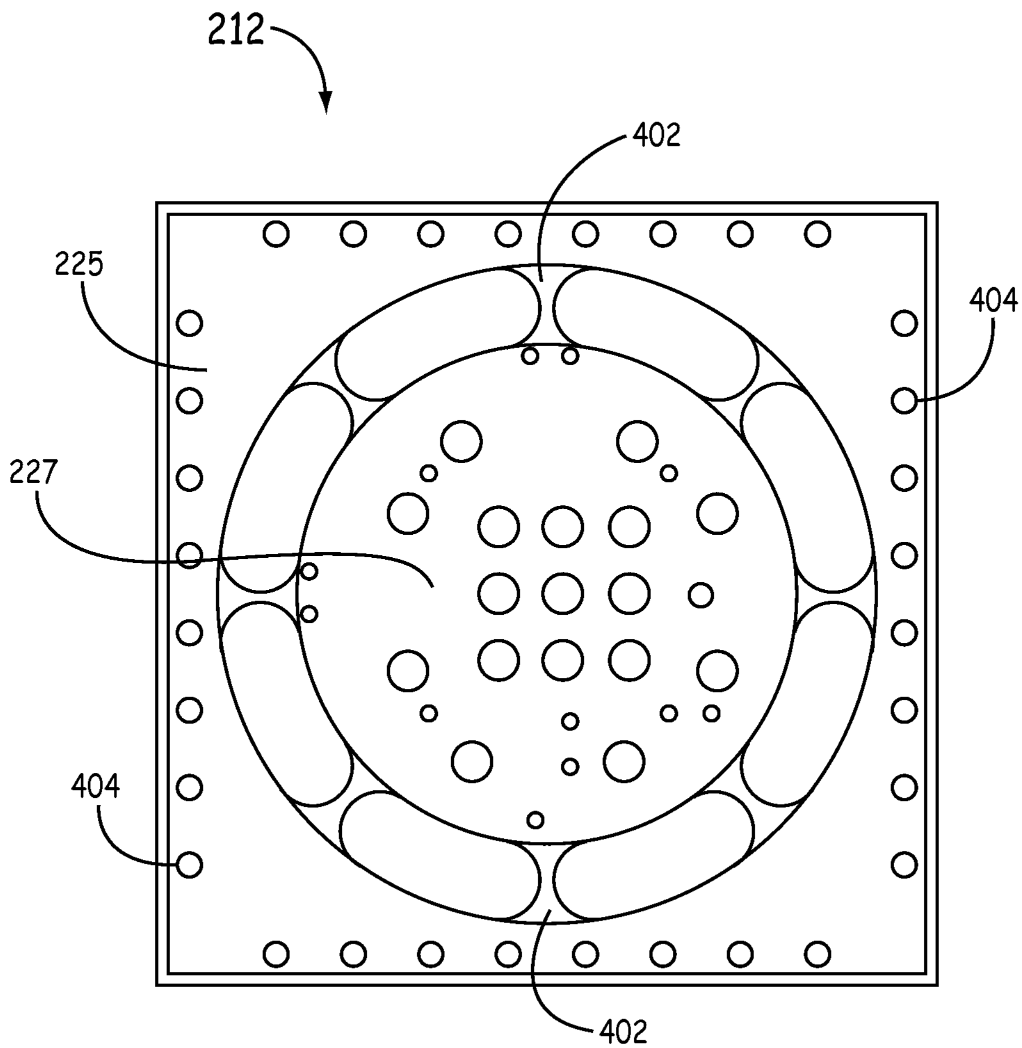

FIG. 4

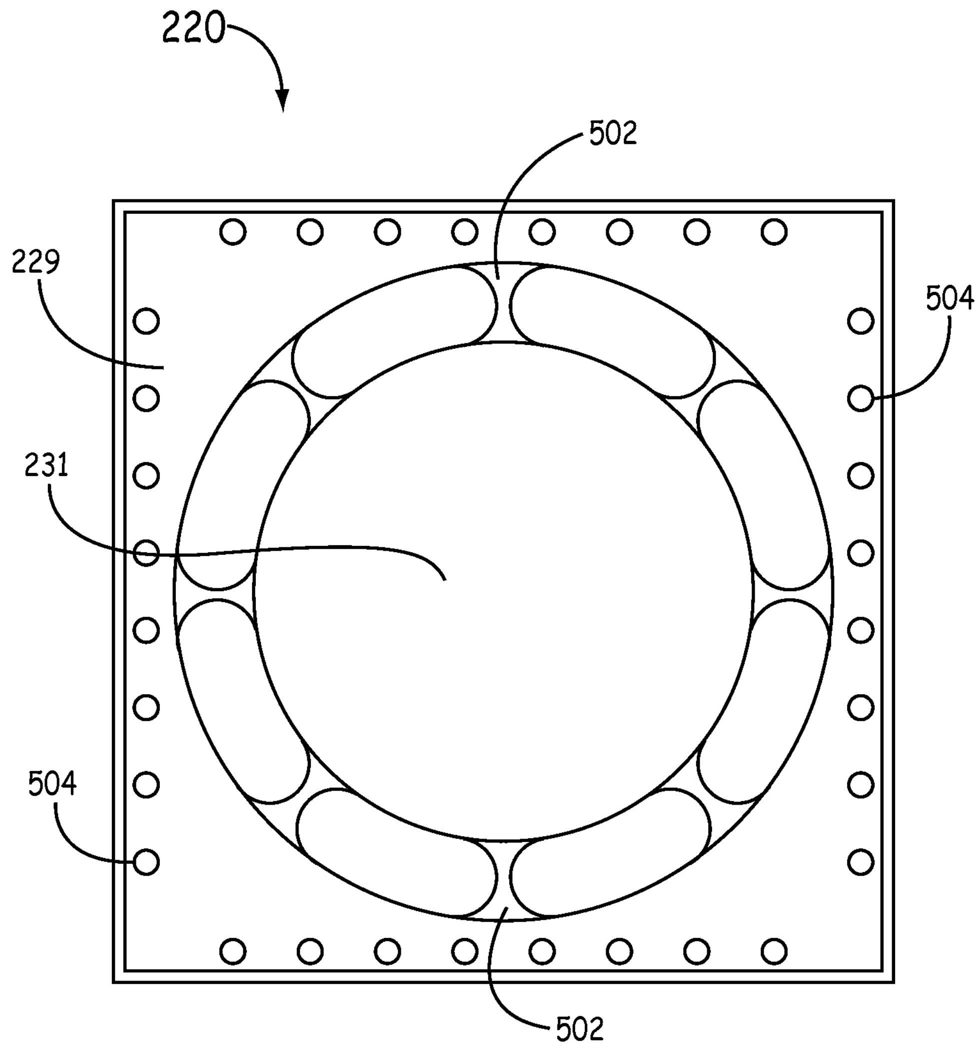

FIG. 5

VAPOR CELL ATOMIC CLOCK PHYSICS PACKAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 13/327,417, filed on Dec. 15, 2011 and claims the benefit of priority to U.S. Provisional Application No. 61/496,517, filed on Jun. 13, 2011, the disclosures of which are hereby incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under W15P7T-10-C-B025 awarded by the US Army. The Government has certain rights in the invention.

BACKGROUND

A physics package for a chip-scale atomic clock can include a laser, waveplate, vapor cell, and a photodetector along with other associated electronics. These components can be housed within a body that can be hermetically seal to create a vacuum within the body.

SUMMARY

In an example, a chip-scale atomic clock physics package is provided. The physics package includes a body defining a cavity having a base surface and one or more side walls. The cavity includes a first step surface and a second step surface defined in the one or more side walls. A first scaffold mounted to the base surface in the cavity. One or more spacers defining an aperture therethrough are mounted to the second step surface in the cavity. A second scaffold is mounted to a first surface of the one or more spacers spans across the aperture of the one or more spacers. A third scaffold is mounted to a second surface of the one or more spacers in the cavity and spans across the aperture of the one or more spacers. Other components of the physics package are mounted to the first, second, and third scaffold.

DRAWINGS

Understanding that the drawings depict only exemplary embodiments and are not therefore to be considered limiting in scope, the exemplary embodiments will be described with additional specificity and detail through the use of the accompanying drawings, in which:

FIG. **1** is a cross-sectional view of an example of a vapor cell atomic clock physics package.

FIG. **2** is a cross-sectional view of another example of a vapor cell atomic clock physics package.

FIG. **3** is a bottom view of an example lower scaffold of the vapor cell atomic clock physics package of FIG. **2**.

FIG. **4** is a top view of an example upper scaffold of the vapor cell atomic clock physics package of FIG. **2**.

FIG. **5** is a bottom view of an example middle scaffold of the vapor cell atomic clock physics package of FIG. **2**.

In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the exemplary embodiments.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in

which is shown by way of illustration specific illustrative embodiments. However, it is to be understood that other embodiments may be utilized and that logical, mechanical, and electrical changes may be made. Furthermore, the method presented in the drawing figures and the specification is not to be construed as limiting the order in which the individual steps may be performed. The following detailed description is, therefore, not to be taken in a limiting sense.

FIG. **1** is a cross-sectional view of an example physics package for a chip-scale atomic clock (CSAC) physics package **100**. The CSAC physics package **100** can include a ceramic body **102** defining a cavity **103** for housing components of the CSAC physics package **100**. The ceramic body **102** including the components in the cavity **103** can comprise a ceramic leadless chip carrier (CLCC) package. The CSAC physics package **100** can also include a non-magnetic (e.g., ceramic) lid **104** configured to fit over the cavity **103** of the ceramic body **102** to form a closed package encasing the cavity **103** and the components therein. In an example, the ceramic lid **104** has a generally planar shape. A solder seal **106** can be used to seal the lid **104** to the body **102**. In an example, the lid **104** can be sealed to the body **102** in a vacuum. In an example, die attach and sealing operations for the CSAC physics package **100** (e.g., for sealing the lid **104** to the body **102**) are accomplished without the use of flux to enable low pressure in the sealed package which can enable lower power operation. This physics package can enable batch vacuum sealing of the lid **104** to the body **102**. The CSAC physics package **100** can also include a getter film **101** coating most of the interior surface of a ceramic lid **104**.

In an example, the ceramic body **102** has one side (e.g., the top) open such that the body **102** defines the cavity **103**. The lid **104** can cover the open side of the body **102** to enclose the cavity **103**. In an example, the cavity **103** has a shape generally pentagonal cross section when viewed from the open side (e.g., top). In another example, the cavity **103** has a generally circular cross-section when viewed from the open side (e.g., top). In any case, the cavity **103** can include a base surface **105** and one or more interior sides **107**. The one or more sides **107** can have one or more steps **109** defined therein for, for example, supporting structures within the cavity of the body **102**.

The CSAC physics package **100** can include one or more scaffolds **108**, **112** for supporting components such as a laser **110**, waveplate **111**, vapor cell **114**, and photodetector **116**. In an example, a scaffold **108**, **112** can include a membrane suspended within a frame. The scaffolds **108**, **112** can also include a stiffening member attached to the membrane to provide additional structure for the membrane. To produce the scaffolds **108**, **112** at a size that can be used for the CSAC physics package **100**, the scaffolds **108**, **112** can be fabricated using semiconductor fabrication processes. Accordingly, the frame and stiffening member can be composed of silicon and the membrane can be composed of polyimide. The polyimide can thermally isolate the stiffening member and components on the scaffolds **108**, **112** from the frame and body **102**.

The CSAC physics package **100** includes a lower scaffold **108** and an upper scaffold **112** that are mounted in the cavity **103**. In an example, the lower scaffold **108** and the upper scaffold **112** can be disposed parallel to one another and parallel to the base surface **105** of the cavity **103**. In this example, the lower scaffold **108** is attached to the base surface **105** of the cavity **103** via a fluxless die attach. In an example, the fluxless die attach can be a plurality of gold (Au) stud bumps. The lower scaffold **108** can function as a support structure for a heater, the laser **110**, and the waveplate **111**. The lower scaffold **108** and components thereon (e.g., laser

110, waveplate 111) can be electrically coupled to pins on the body 102 via wire bonds to a pad on a lower step 109 of the inner side surface 107 of the cavity 103 of the ceramic body 102.

The lower scaffold 108 can include a first side 113 that opposes the base surface 105 and a second side 115 that is reverse of the first side 113 and facing the lid 104 and the upper scaffold 112. In an example, the frame 119 and the stiffening member 123 are on the first side 113. The stiffening member 123 can define a plurality of apertures to reduce the mass thereof. In an example, the laser 110 and the waveplate 111 are mounted to the second side 115. Moreover, the waveplate 111 can be disposed overtop of the laser 110 such that a beam of the laser 110 propagates through the waveplate 111. In an example, the laser 110 can be solder bonded to the second side 115 using, for example, flip-chip mounting. Additionally, a plurality of solder balls 117 can be attached to the second side 115. The plurality of solder balls 117 can be disposed around the laser 110 and project a height above the second side 115 that is higher than the laser 110 such that the waveplate 111 can be soldered to the plurality of solder balls 117 and disposed overtop of the laser 110. In an example, the plurality of solder balls 117 can be formed using a jetting process tuned to produce solder balls of the desired size. In an example, the solder balls 117 can be formed of a solder having a high temperature melting point, such that, once formed on the scaffold 108, the solder balls 117 generally maintain their structure during further fabrication of the CSAC physics package 100.

In an example, a first portion of the solder balls 117 on the second side 115 have a lower height above the second side 115 than a second portion of the solder balls 117. Moreover, the first portion of solder balls 117 can be disposed to attach about a first edge of the waveplate 111 and a second portion of the solder balls 117 can be disposed to attach about a second edge of the waveplate 111. The differing height of the first and second portions of the solder balls 117 can cause the waveplate 111 to be disposed at an angle with respect to the second side 115. Orienting the waveplate 111 at an angle can direct laser reflections off of the waveplate 111 away from the laser 110. In an example, the laser 110 can be a vertical cavity surface emitting laser (VCSEL). In an example, the waveplate 111 can be a quarter waveplate.

In an example, the upper scaffold 112 can function as a support structure for an alkali vapor cell 114 and a photodetector 116. The upper scaffold 112 can be supported on an upper step 109 (e.g., an upper shelf) of the inner side surface 107 of the cavity 103 of the ceramic body 102. Moreover, by forming steps 109 in the sides 107 of the cavity 103, the body 102 can be used to, at least partially, space the upper scaffold 112 from the lower scaffold 108. In an example, the upper scaffold 112 can be attached to one or more spacers 118 (e.g., leg structures, washer) extending up from the upper step 109 of the cavity 103 to further space the upper scaffold 112 from the lower scaffold 108. In an example, the spacer 118 can be composed of ceramic. In an example, the spacer 118 can have a ring shape (e.g., a pentagon ring shape) defining an aperture therein. The spacer 118 can be disposed around the vapor cell 114 such that the vapor cell 114 is within the aperture defined in the spacer 118.

In an example, the spacer 118 can function to reduce fatigue on the joint(s) coupling the upper scaffold 112 to the upper step 109. The spacer 118 can reduce fatigue by being composed of a material that has a thermal expansion coefficient that is in between the thermal expansion coefficient of the body 102 and the thermal expansion coefficient of the upper scaffold 112. Accordingly, as the body 102 and the upper scaffold 112 expand and contract due to temperature changes, the spacer 118 can absorb some of the changes. For example, the body 102 can be composed of a ceramic having a thermal expansion coefficient of 7 ppm per degree Celsius, the spacer 118 can have a thermal expansion coefficient of 5 ppm per degree Celsius, and the upper scaffold 112 can have a thermal expansion coefficient of 3 ppm per degree Celsius. In another example, the spacer 118 can be formed of the same material as the body 102 and the lid 104. The spacer 118 can provide mechanical support and electrical contact for the upper scaffold 112. In some examples, the spacer 118 can also provide mechanical support and electrical contact for additional electronic components such as surface mount technology (SMT) electronics 120.

The combination of the upper scaffold 112 and the ceramic spacer 118 can traverse the cavity 103 of the body 102 and attach to the upper step 109. In an example, the upper scaffold 112 can be attached to the spacer 118 via fluxless die attach. The spacer 118 can be attached via fluxless die attach to the body 102, for example, at the upper step 109 of the body 102. In an example, the fluxless die attach can be a plurality of gold (Au) stud bumps.

The upper scaffold 112 can include a first side 121 that opposes the lid 104 and a second side 124 that is reverse of the first side 121 and facing the lower scaffold 108. In an example, the frame 125 and the stiffening member 127 are on the first side 121. The stiffening member 127 can define a plurality of apertures to reduce the mass thereof. In an example, the photodetector 116 and the vapor cell 114 are mounted to the second side 124. Moreover, the vapor cell 114 can be disposed overtop of the photodetector 116 and aligned with the laser 110 and waveplate 111 such that a beam from the laser 110 propagates through the waveplate 111, then through the vapor cell 114 and can be detected by the photodetector 116. In an example, the photodetector 116 can be solder bonded to the second side 124 using, for example, flip-chip mounting. A plurality of solder balls 126 can be attached to the second side 124. The plurality of solder balls 126 can be disposed around the photodetector 116 and can project a height above the second side 124 that is higher than the photodetector 116 such that the vapor cell 114 can be soldered to the plurality of solder balls 126 and disposed overtop of the photodetector 116. In an example, the vapor cell 114 can be disposed at least 200 micrometers apart from the photodetector 116. This gap can enable flux to be flushed from between the vapor cell 114 and the photodetector 116. In an example, the plurality of solder balls 126 can be formed using a jetting process tuned to produce solder balls of the desired size. In an example, the solder balls 126 can be formed of a solder having a high temperature melting point, such that, once formed on the scaffold 112, the solder balls 126 generally maintain their structure during further fabrication of the CSAC physics package 100. In an example, the vapor cell 114 can be an alkali vapor cell containing rubidium atoms.

In an example, the upper scaffold 112 is in a flipped position with respect to the lower scaffold 108. That is, the frame 119 of the lower scaffold 108 projects in the opposite direction from the frame 125 of the upper scaffold 112. Additionally, the components (e.g., laser 110, waveplate 111, and photodetector 116, vapor cell 114) are on the side of their respective scaffold 108, 112 that is the reverse of the side having the frame 119, 125. Accordingly, in order to mount the scaffolds 108, 112 with the components all within the space between the scaffolds 108, 112, the scaffolds are disposed in a flipped position with respect to one another. Additionally, the components (e.g., the laser 110, waveplate 111, photodetector **116**, and vapor cell **114**) can be disposed in between the polyimide layers of the scaffolds **108**, **112**.

The CSAC physics package **100** can include an input/output (I/O) solder pad **122** on a bottom portion of the body **102**. Thus, wires can attach to the CSAC physics package **100** on a bottom portion thereof. In an example, interconnects between the I/O solder pad **122** and internal components (e.g., laser **110**, waveplate **111**, and photodetector **116**, vapor cell **114**) can be routed through the body **102**. In some examples, interconnects for components on the upper scaffold **112** (e.g., photodetector **116**) can be routed through the spacer **118**. Thus, the spacer **118** can include electrical traces on an internal or outside portion thereof.

In an example, a magnetic coil can be disposed about (e.g., within) the spacer **118** such that the magnetic coil extends around the vapor cell **114**. The magnetic coil can be configured to provide a bias field for the vapor cell **114**. In an example, the magnetic coil can be integrated into (e.g., internal to) the spacer **118**.

FIG. **2** is a cross-sectional view of another example physics package for a CSAC physics package **200**. The CSAC physics package **200** can include a ceramic body **202** defining a cavity **203** for housing components of the CSAC physics package **200**. The ceramic body **202** including the components in the cavity **203** can comprise a ceramic leadless chip carrier (CLCC) package. The CSAC physics package **200** can also include a non-magnetic (e.g., ceramic) lid **204** configured to fit over the cavity **203** of the ceramic body **202** to form a closed package encasing the cavity **203** and the components therein. In an example, the ceramic lid **204** has a generally planar shape. A solder seal **206** can be used to seal the lid **204** to the body **202**. In an example, die attach and sealing operations for the CSAC physics package **200** (e.g., for sealing the lid **204** to the body **202**) are accomplished without the use of flux to enable low pressure in the sealed package which can enable lower power operation. In an example, the lid **204** can be sealed to the body **202** in a vacuum. This physics package can enable batch vacuum sealing of the lid **204** to the body **202**. The CSAC physics package **200** can also include a getter film coating most of the interior surface of a ceramic lid **204**.

In an example, the ceramic body **202** has one side (e.g., the top) open such that the body **202** defines the cavity **203**. The lid **204** can cover the open side of the body **202** to enclose the cavity **203**. In an example, the cavity **203** has a shape generally pentagonal cross section when viewed from the open side (e.g., top). In another example, the cavity **203** has a generally circular cross-section when viewed from the open side (e.g., top). In any case, the cavity **203** can include a base surface **205** and one or more interior sides **207**. The one or more sides **207** can have one or more steps **209** defined therein for, for example, supporting structures within the cavity of the body **202**.

The CSAC physics package **200** can include one or more scaffolds **208**, **212**, **220** for supporting components such as a laser **210**, waveplate **211**, vapor cell **214**, and photodetector **216**. In an example, a scaffold **208**, **212**, **220** can include a membrane suspended between a frame. The scaffolds **208**, **212**, **220** can also include a stiffening member attached to the membrane to provide additional structure for the membrane. To produce the scaffolds **208**, **212**, **220** at a size that can be used for the CSAC physics package **200**, the scaffolds **208**, **212**, **220** can be fabricated using semiconductor fabrication processes. Accordingly, the frame and stiffening member can be composed of silicon and the membrane can be composed of polyimide. The polyimide can thermally isolate the stiffening member and components on the scaffolds **208**, **212**, **220** from the frame and body **202**.

The CSAC physics package **200** includes a lower scaffold **208**, an upper scaffold **112**, and a middle scaffold **220** that are mounted in the cavity **203**. In an example, the lower scaffold **208**, the upper scaffold **212**, and the middle scaffold **220** can be disposed parallel to one another and parallel to the base surface **205** of the cavity **203**. In this example, the lower scaffold **208** is attached to the base surface **205** of the cavity **203** via fluxless die attach. In an example, the fluxless die attach can be a plurality of gold (Au) stud bumps. The lower scaffold **208** can function as a support structure for a heater and the laser **210**. The lower scaffold **208** and components thereon (e.g., laser **210**) can be electrically coupled to pins on the body **202** via wire bonds to a pad on a lower step **209** of the inner side surface **207** of the cavity **203** of the ceramic body **202**. In an example, the laser **210** can be a vertical cavity surface emitting laser (VCSEL).

The lower scaffold **208** can include a first side **213** that opposes the base surface **205** and a second side **215** that is reverse of the first side **213** and facing the lid **204**, the middle scaffold **220**, and the upper scaffold **212**. In an example, the frame **219** and the stiffening member **223** are on the first side **213**. The stiffening member **223** can define a plurality of apertures to reduce the mass thereof. In an example, the laser **210** is mounted to the second side **215**. In an example, the laser **210** can be solder bonded to the second side **215** using, for example, flip-chip mounting.

FIG. **3** is a bottom view of an example lower scaffold **208**. As mentioned above, the lower scaffold **208** can include a membrane having a frame **219** and a stiffening member **223** attached thereto. The frame **219** and the stiffening member **223** can be separated from one another on the membrane with a plurality of tethers **302** of the membrane extending between the frame **219** and the stiffening member **223**. A plurality of stud bumps **304** can be on the frame **219** to attach the frame **219** to the body **202**. Components (e.g., the laser **210**) can be mounted on the membrane in the area of the stiffening member **223**. Traces can extend across the tethers **302** to electrically couple the components on the stiffening member to the stud bumps **304**.

The upper scaffold **212** and middle scaffold **220** can be mounted on opposite sides of one or more spacers **218** (e.g., leg structure, washer). The upper scaffold **212** can function as a support structure for the photodetector **216** and the middle scaffold **220** can function as a support structure for the waveplate **211**. In addition, the upper scaffold **212** and middle scaffold **220** can function as a support structure for the alkali vapor cell **214**. In particular, the vapor cell **214** can be supported between the upper scaffold **212** and the middle scaffold **220**. Accordingly, the vapor cell **214** attached to the upper scaffold **212** on one end and the middle scaffold **220** on the opposite end. Moreover, the vapor cell **214** can be disposed within an aperture of the spacer **218**. Accordingly, the upper scaffold **212**, middle scaffold **220**, and the spacer **218** can form a support structure for the vapor cell **214**. In an example, a heater for the upper surface of the vapor cell **214** can be mounted on the upper scaffold **212** and a heater for the lower surface of the vapor cell **214** can be mounted on the middle scaffold **220**. In another example, one or more heaters can be fabricated on one or more surfaces of the vapor cell **214**. In an example, the spacer **218** can have a ring shape (e.g., a pentagon ring shape) defining an aperture therein. The spacer **218** can be disposed around the vapor cell **214** such that the vapor cell **214** is within the aperture defined in the spacer **218**.

In an example, the spacer **218** can also function to reduce fatigue on the joint(s) coupling the upper scaffold **212** and the middle scaffold **220** to the upper step **209**. The spacer **218** can reduce fatigue by being composed of a material that has a thermal expansion coefficient that is in between the thermal expansion coefficient of the body **202** and the thermal expansion coefficient of the upper scaffold **212** and middle scaffold **220**. Accordingly, as the body **202**, the upper scaffold **212**, and the middle scaffold **220** expand and contract due to temperature changes, the spacer **218** can absorb some of the changes. For example, the body **202** can be composed of a ceramic having a thermal expansion coefficient of 7 ppm per degree Celsius, the spacer **218** can have a thermal expansion coefficient of 5 ppm per degree Celsius, and the upper scaffold **212** and middle scaffold **220** can have a thermal expansion coefficient of 3 ppm per degree Celsius. In another example, the spacer **218** can be formed of the same material as the body **202** and the lid **204**. The spacer **218** can provide mechanical support and electrical contact for the upper scaffold **212** and middle scaffold **220**. In some examples, the spacer **218** can also provide mechanical support and electrical contact for additional electronic components such as surface mount technology (SMT) electronics.

As mentioned above, the spacer **218** with the upper scaffold **212** and middle scaffold **220** mounted thereon can be mounted to a step **209** in the body **202**. In particular, the spacer **218** can be mounted to an upper step **209**. Steps **209** in the sides **209** of the cavity **203** can be used to, at least partially, space the upper scaffold **212** and middle scaffold **220** from the lower scaffold **208**. The spacer **218** can extend up from the upper step **209** of the cavity **203** to further space the upper scaffold **212** from the lower scaffold **208** and middle scaffold **220** and provide space for the vapor cell **214** between the middle scaffold **220** and the upper scaffold **214**. In an example, the spacer **218** can be composed of ceramic.

The combination of the upper scaffold **212** and the ceramic spacer **218** can traverse the cavity **203** of the body **202** on a top portion of the spacer **218**. Likewise, the middle scaffold **220** and the ceramic spacer **218** can traverse the cavity **203** of the body **202** on a bottom portion of the spacer **218**. In an example, the upper scaffold **212** and the middle scaffold **220** can be attached to the spacer **218** via fluxless die attach. The spacer **218** can be attached via fluxless die attach to the upper step **209** of the body **202**. In an example, the fluxless die attach can be a plurality of gold (Au) stud bumps.

The upper scaffold **212** can include a first side **221** that opposes the lid **204** and a second side **224** that is reverse of the first side **221** and facing the middle scaffold **220** and the lower scaffold **208**. In an example, the frame **225** and the stiffening member **227** are on the first side **221**. The stiffening member **227** can define a plurality of apertures to reduce the mass thereof. In an example, the photodetector **216** and the vapor cell **214** are mounted to the second side **224**. Moreover, the vapor cell **214** can be disposed overtop of the photodetector **216** and aligned with the laser **210** and waveplate **211** such that a beam from the laser **210** propagates through the waveplate **211**, then through the vapor cell **214** and can be detected by the photodetector **216**. In an example, the photodetector **216** can be solder bonded to the second side **224** using, for example, flip-chip mounting. A plurality of solder balls **226** can be attached to the second side **224**. The plurality of solder balls **226** can be disposed around the photodetector **216** and can project a height above the second side **224** that is higher than the photodetector **216** such that the vapor cell **214** can be soldered to the plurality of solder balls **224** and disposed overtop of the photodetector **216**. In an example, the vapor cell **214** can be disposed at least 200 micrometers apart from the photodetector **216**. This gap can enable flux to be flushed from between the vapor cell **214** and the photodetector **216**. In an example, the plurality of solder balls **226** can be formed using a jetting process tuned to produce solder balls of the desired size. In an example, the solder balls **226** can be formed of a solder having a high temperature melting point, such that, once formed on the scaffold **212**, the solder balls **224** generally maintain their structure during further fabrication of the CSAC physics package **200**. In an example, the vapor cell **214** can be an alkali vapor cell containing rubidium atoms.

In an example, the upper scaffold **212** is in a flipped position with respect to the lower scaffold **208** and the middle scaffold **220**. That is, the frame **219** on the lower scaffold **208** and the middle scaffold **220** project in the opposite direction from the frame **225** of the upper scaffold **212**. Additionally, the vapor cell **214** can be disposed in between the polyimide layers of the upper scaffold **212** and middle scaffold **220**.

FIG. **4** is a top view of an example upper scaffold **212**. As mentioned above, the upper scaffold **212** can include a membrane having a frame **225** and a stiffening member **227** attached thereto. The frame **225** and the stiffening member **227** can be separated from one another on the membrane with a plurality of tethers **402** of the membrane extending between the frame **225** and the stiffening member **227**. A plurality of stud bumps **404** can be on the frame **225** to attach the frame **225** to the body **202**. Components (e.g., the vapor cell **214**) can be mounted on the membrane in the area of the stiffening member **227**. Traces can extend across the tethers **402** to electrically couple the components on the stiffening member to the stud bumps **404**.

The middle scaffold **220** can include a first side **228** that faces the lid **204** and opposes the upper scaffold **212** and a second side **230** that faces the base surface **205** and opposes the lower scaffold **208**. The middle scaffold **220** can be mounted to the spacer **218** on the first side **228** of the scaffold **220**.

In an example, the frame **229** and the stiffening member **231** are on the second side **230**. The stiffening member **231** can define a plurality of apertures to reduce the mass thereof. The vapor cell **214** can also be mounted on the first side **228** of the middle scaffold **220**. The waveplate **211** can be mounted on the second side **230** of the middle scaffold **220**. In an example, a plurality of tilting features **232** can be fabricated into the second side **230** of the middle scaffold **220**. The waveplate **211** can be mounted to these tilting features **232**, which can be configured to orient the waveplate **211** at an angle with respect to the middle scaffold **220**. For example, a first feature can have a lower height than a second feature, and a first edge of the waveplate **211** can be attached to the first feature and a second edge of the waveplate **211** can be attached to the second feature. Orienting the waveplate **211** at an angle can direct laser reflections off of the waveplate **211** away from the laser **210**. In an example, the waveplate **211** can be a quarter waveplate.

FIG. **5** is a bottom view of an example middle scaffold **220**. As mentioned above, the middle scaffold **220** can include a membrane having a frame **229** and a stiffening member **231** attached thereto. The frame **229** and the stiffening member **231** can be separated from one another on the membrane with a plurality of tethers **502** of the membrane extending between the frame **229** and the stiffening member **231**. A plurality of stud bumps **504** can be on the frame **229** to attach the frame **229** to the body **202**. Components (e.g., the vapor cell **214**) can be mounted on the membrane in the area of the stiffening member **223**. Additionally, other components (e.g., the waveplate **211**) can be mounted on the stiffening member **231**.

In an example, a magnetic coil **234** can be disposed about (e.g., within) the spacer **218** such that the magnetic coil extends around the vapor cell **214**. The magnetic coil can be configured to provide a bias field for the vapor cell **214**. In an example, the magnetic coil **234** can be integrated into (e.g., internal to) the spacer **218**.

In an example, a second photodetector **236** can be configured to detect reflections of the laser **210** from the waveplate **211**. The second photodetector **236** can be used to control the light power output of the laser **210**. In particular, based on the strength of the light reflected from the waveplate **211**, the power output of the laser **210** can be determined and controlled accordingly. The second photodetector **236** can be mounted to the lower scaffold **208**. In particular, the second photodetector **236** can be mounted to the second side **215** of the lower scaffold **208** adjacent the laser **210**.

The CSAC physics package **200** can include an input/output (I/O) solder pad **222** on a bottom portion of the body **202**. Thus, a bottom portion of the CSAC physics package **200** can be attached to a circuit board. In an example, interconnects between the I/O solder pad and internal components (e.g., laser **210**, waveplate **211**, and photodetector **216**, vapor cell **214**) can be routed through the body **202**. In some examples, interconnects for components on the upper scaffold **212** (e.g., photodetector **216**) and middle scaffold **220** (e.g., heater) can be routed through the spacer **218**. Thus, the spacer **218** can include electrical traces on an internal or outside portion thereof.

In an example, to manufacture the CSAC physics package **100** or CSAC physics package **200**, the scaffolds, spacer, body, and lid can be formed and combined together. The scaffolds can be created and assembled at the wafer level. For example, a scaffold can comprise a silicon wafer having a polyimide membrane on a first side thereof. The side of the scaffold having the polyimide member can be referred to as the "front side" of the scaffold. The front side of the scaffold can then be etched to form the frame and stiffening member having holes therein. As mentioned above, adding the polyimide membrane and etching the scaffold can occur on wafer having a plurality of un-diced scaffold dies thereon.

Once etched, components can be attached to the scaffold. For the lower scaffold **108** of the CSAC physics package **100**, the etched wafer can have the heater, laser **110**, and waveplate **111** attached thereto. The laser **110** and heater can be, for example, flip-chip mounted to the lower scaffold **108**. The plurality of solder balls **117** can be attached using the jetting process mentioned above. Then, the waveplate **111** can be attached to the solder balls **117** using a solder, an epoxy, or other die attach compound. For the upper scaffold **112**, the etched wafer can have the photodetector **116** attached thereto, along with the solder balls **126**, and then the vapor cell **114**. The photodetector **116** can be flip-chip mounted, and the vapor cell **114** can be attached using a solder, an epoxy, or other die attach compound. In an example, the photodetector **116** can be electrically coupled to the upper scaffold **112** with a wirebond.

For the lower scaffold **208** of the CSAC physics package **200**, the etched wafer can have the laser **210** and the second photodetector **236** attached thereto. The laser **210** and second photodetector **236** can be, for example, flip-chip mounted to the lower scaffold **208**. For the middle scaffold **220**, the plurality of features **232** can be fabricated therein using standard semiconductor processes. The waveplate **211** can then be attached to the scaffold **220** (e.g., to the plurality of features **232**) using, for example, an epoxy. For the upper scaffold **212**, the etched wafer can have the photodetector **216** attached thereto, along with the solder balls **226**, and then the vapor cell **214**. The photodetector **216** can be flip-chip mounted, and the vapor cell **214** can be attached using a solder, an epoxy, or other die attach compound. In an example, the photodetector **216** can be electrically coupled to the upper scaffold **212** with a wirebond.

These components can be added before singulation of the wafers. The wafers can then be singulated to form the individual scaffolds. In an example, the wafers can be singulated using a dry dicing process. The scaffolds can then have solder balls attached for electrical and mechanical attachment of the scaffolds. In an example, after the scaffolds have been fabricated they can be tested and have operational burn-in performed.

The lower scaffold **108** of the CSAC physics package **100** can be attached to the base surface **105** (e.g., bottom, floor) of the body **102** using fluxless die attach (e.g., gold (Au) stud bumps). Wirebonds for the lower scaffold **108** can be attached to the appropriate pads on the body **102** at, for example, the lower step **109**. The upper scaffold **112** can be attached to spacer **118** or directly to the body **102** using solder, gold (Au) stud bumps, or other fluxless die attach compounds.

The SMT electronics **120** can be attached to the spacer **118**. The spacer **118** can be manufactured in array form suitable for batch die/component attach, and singulated to separate. The spacer **118** can be singulated, the upper scaffold **112** can be attached, and the combination can be attached to the upper step **109** in the body **102** using fluxless die attach (e.g., gold (Au) stud bumps). In an example, this die attach can provide both mechanical and electrical feedthru. In another example, this die attach can provide mechanical die attach with no electrical feedthru and the electrical attach can be done with wirebonds.

The lower scaffold **208** of the CSAC physics package **200** can be attached to the base surface **205** (e.g., bottom, floor) of the body **202** using fluxless die attach (e.g., gold (Au) stud bumps). Wirebonds for the lower scaffold **208** can be attached to the appropriate pads on the body **202** at, for example, the lower step **209**.

The spacer **218** can be manufactured in array form suitable for batch die/component attach, and singulated to separate. Once singulated, the upper scaffold **212** and the middle scaffold **220** can be attached to opposite ends of the spacer **218**. The vapor cell **214** can be positioned in between the upper scaffold **212** and the middle scaffold **220** in an aperture formed by the spacer **118**. The vapor cell **214** can be attached to the middle scaffold **220** and/or the upper scaffold **212** if not already attached. The upper scaffold **212** and middle scaffold **220** can be attached to spacer **218** using solder, gold (Au) stud bumps, or other fluxless die attach compounds. The combined construction of the spacer **218**, upper scaffold **212**, middle scaffold **220** and vapor cell **214** can then be mounted to a step **209** (e.g., the upper step) of the body **202**. The spacer **218** can be attached to step **209** using solder, gold (Au) stud bumps, or other fluxless die attach compounds. In an example, this die attach can provide both mechanical and electrical feedthru. In another example, this die attach can provide mechanical die attach with no electrical feedthru and the electrical attach can be done with wirebonds.

The lid **204** can be coated with appropriate material (e.g., titanium, etc.) for a getter. In an example, the lid **204** can be coated by sputter depositing the material for the getter. After activating the getter in vacuum, the lid **204** can be sealed to the body **202** with solder.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiments shown. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A chip-scale atomic clock physics package comprising:

a body defining a cavity including a base surface and one or more side walls, wherein the cavity includes a first step surface and a second step surface defined in the one or more side walls;

a lid covering an open side of the cavity to enclosed a volume defined by the cavity;

a first scaffold mounted to the base surface in the cavity;

a laser mounted to the first scaffold;

one or more conductive pads on the first step surface;

one or more wire bonds extending from the first scaffold to the one or more conductive pads, the one or more wire bonds electrically coupling the laser to the one or more conductive pads;

one or more interconnects disposed within the body and extending from the one or more conductive pads on the first step surface to one or more external pads on an exterior surface of the body;

one or more spacers defining an aperture therethrough, the one or more spacers having a first surface facing the base surface of the cavity and a second surface facing the lid, wherein the first surface of the one or more spacers is mounted to the second step surface in the cavity;

a second scaffold mounted to the first surface of the one or more spacers in the cavity and spanning across the aperture of the one or more spacers;

a third scaffold mounted to the second surface of the one or more spacers in the cavity and spanning across the aperture of the one or more spacers;

a vapor cell mounted between the second scaffold and the third scaffold and within the aperture defined by the one or more spacers, wherein the vapor cell is mounted to the second scaffold on one side and to the third scaffold on the other side;

a photodetector mounted to the third scaffold; and

a waveplate, wherein the laser, waveplate, photodetector, and vapor cell are disposed such that a beam from the laser can propagate through the waveplate and the vapor cell and be detected by the photodetector.

2. The chip-scale atomic clock physics package of claim 1, wherein the lid has a generally planar geometry.

3. The chip-scale atomic clock physics package of claim 1, wherein the third scaffold is disposed in a flipped position with respect to the second scaffold.

4. The chip-scale atomic clock physics package of claim 1, wherein the combination of the one or more spacers and the second scaffold spans the cavity defined by the body, and wherein the combination of the one or more spacers and the third scaffold spans the cavity defined by the body.

5. The chip-scale atomic clock physics package of claim 4, wherein the one or more spacers have a general ring shape, wherein the one or more spacers are attached to opposing sides of the cavity.

6. The chip-scale atomic clock physics package of claim 1, further comprising a magnetic coil about the one or more spacers.

7. The chip-scale atomic clock physics package of claim 1, wherein the body is composed of a ceramic and wherein the one or more spacers are composed of a ceramic.

8. The chip-scale atomic clock physics package of claim 1, wherein the waveplate is mounted to the second scaffold.

9. The chip-scale atomic clock physics package of claim 8, wherein the second scaffold includes a first surface facing the third scaffold and a second surface facing the first scaffold, wherein the vapor cell is mounted to the first surface of the second scaffold and the waveplate is mounted to the second surface of the second scaffold.

10. The chip-scale atomic clock physics package of claim 1, wherein the vapor cell is disposed overtop of the photodetector on the third scaffold.

11. The chip-scale atomic clock physics package of claim 1, wherein the one or more external pads are on an external surface of the body opposite the lid.

12. The chip-scale atomic clock physics package of claim 1,

wherein the one or more spacers include second one or more interconnects extended within the one or more spacers, the second one or more interconnects electrically coupling the second scaffold and the third scaffold to one or more pads on the second step surface,

wherein the second one or more interconnects electrically couple the one or more external pads to the one or more pads on the second step surface.

13. A chip-scale atomic clock physics package comprising:

a body defining a cavity;

a lid covering the cavity;

a first scaffold mounted in the cavity;

a laser mounted to the first scaffold;

one or more spacers mounted in the cavity, the one or more spacers defining an aperture therethrough;

a magnetic coil integrated within the one or more spacers;

a second scaffold mounted to the one or more spacers in the cavity and spanning the aperture in the one or more spacers;

a third scaffold mounted to the one or more spacers in the cavity and spanning the aperture in the one or more spacers;

a vapor cell mounted between the second scaffold and the third scaffold and within the aperture defined by the one or more spacers, wherein the vapor cell is mounted to the second scaffold on one side and to the third scaffold on the other side;

a photodetector mounted to the third scaffold; and

a waveplate, wherein the laser, waveplate, photodetector, and vapor cell are disposed such that a beam from the laser can propagate through the waveplate and the vapor cell and be detected by the photodetector.

14. The chip-scale atomic clock physics package of claim 13, wherein the magnetic coil extends around the vapor cell and is configured to provide a bias field for the vapor cell.

15. The chip-scale atomic clock physics package of claim 13, comprising:

one or more interconnects extending from external pads on the body to internal pads in the cavity, wherein the magnetic coil integrated within the one or more spacers is electrically coupled to the internal pads such that the magnetic coil is electrically coupled to the external pads through the one or more interconnects.

16. The chip-scale atomic clock physics package of claim 1, wherein the body is composed of a ceramic and wherein the one or more spacers are composed of a ceramic.

17. A chip-scale atomic clock physics package comprising:

a body defining a cavity;

a lid covering the cavity;

a first scaffold mounted in the cavity;

a laser mounted to the first scaffold;

a first photodetector mounted to the first scaffold;

one or more spacers mounted in the cavity and defining an aperture therethrough;

a second scaffold spanning the cavity and mounted to the one or more spacers in the cavity;

a waveplate mounted to the second scaffold;

a third scaffold spanning the cavity and mounted to the one or more spacers in the cavity;

a vapor cell mounted between the second scaffold and the third scaffold and within the aperture defined by the one or more spacers, wherein the vapor cell is mounted to the second scaffold on one side and to the third scaffold on the other side;

a second photodetector mounted to the third scaffold; and

wherein the laser, waveplate, second photodetector, and vapor cell are aligned such that a beam from the laser can propagate through the waveplate and the vapor cell and be detected by the second photodetector, and wherein the first photodetector is disposed to sense reflections from the laser off of the waveplate.

18. The chip-scale atomic clock physics package of claim **17**, wherein the first photodetector is disposed such that an output from the first photodetector can be used to determine a power output of the laser, and the power output can be used to control the laser.

19. The chip-scale atomic clock physics package of claim **17**, wherein the waveplate is oriented at an angle with respect to the beam from the laser such that reflections from the beam are directed away from the laser, wherein the first photodetector is disposed in accordance with the angle of the waveplate in order to sense the reflections from the waveplate.

20. The chip-scale atomic clock physics package of claim **17**, wherein the second scaffold includes a first surface facing the third scaffold and a second surface facing the first scaffold, wherein the vapor cell is mounted to the first surface of the second scaffold and the waveplate is mounted to the second surface of the second scaffold.

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